



ARES Peer Review

December 2, 2003

**Axel zur Loye
Cummins Inc.**

**DOE Cooperative Agreement
DE-FC02-01CH11078**



Outline



- Project description and goals/objectives
- Project Team/Partnerships
- Task definition and activities by task
- Milestones completed and planned
- Key technical barriers and the strategies to overcome them
- Project risks
- Impact of this project on the goals of the Distributed Energy Program
- Summary



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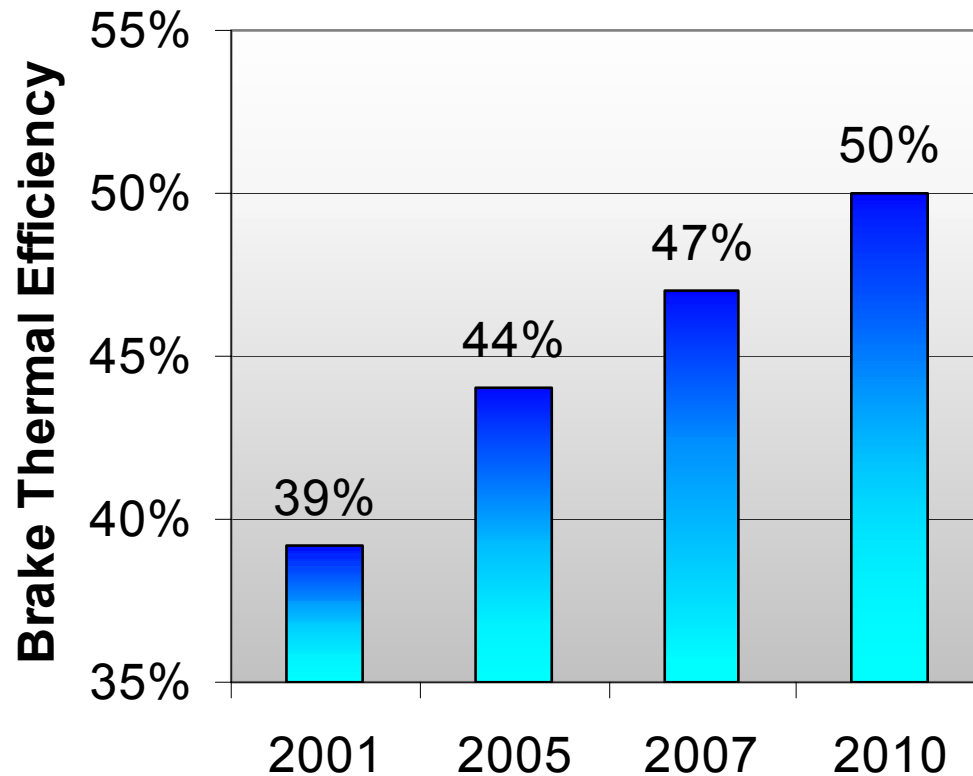
Key ARES Program Goals for 2010:

50% Efficiency at 0.1 g/hp-hr NO_x

10% lower operating cost, Increased fuel flexibility



Cummins Targets



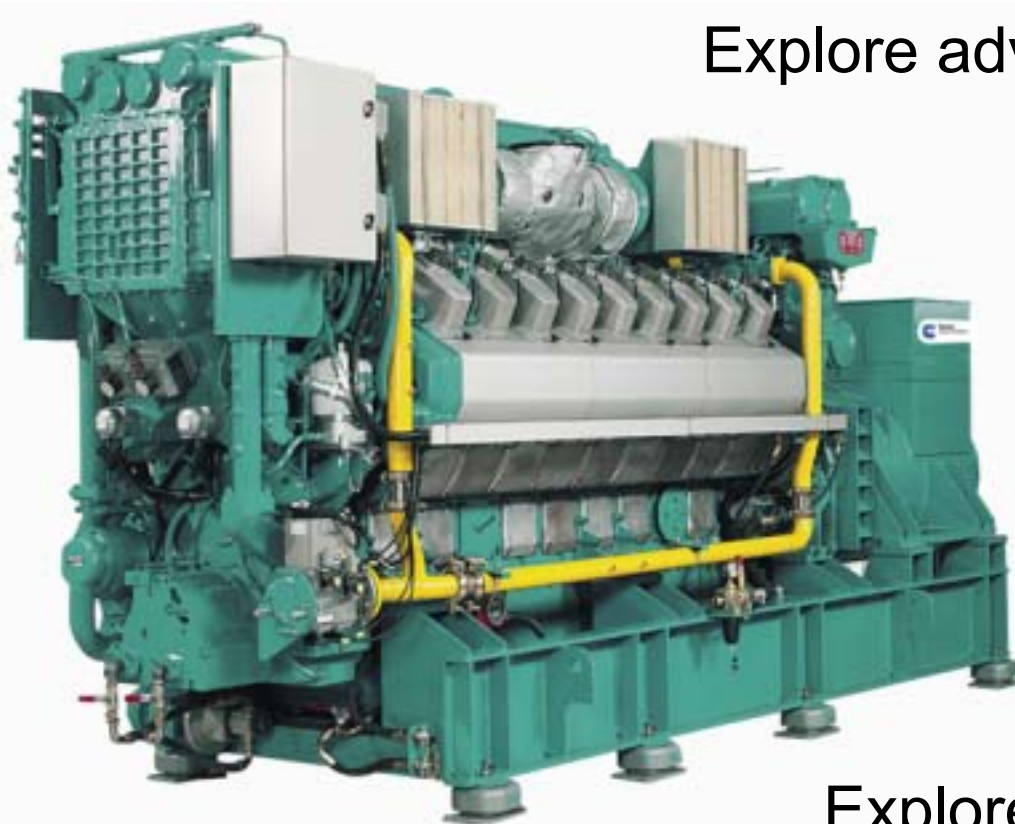
Planned work is split into 3 phases.

Each phase ends with a Field test to demonstrate:

1. 44% BTE in 2005
2. 47% BTE in 2007
3. 50% BTE in 2010



Strategy for achieving ARES goals:



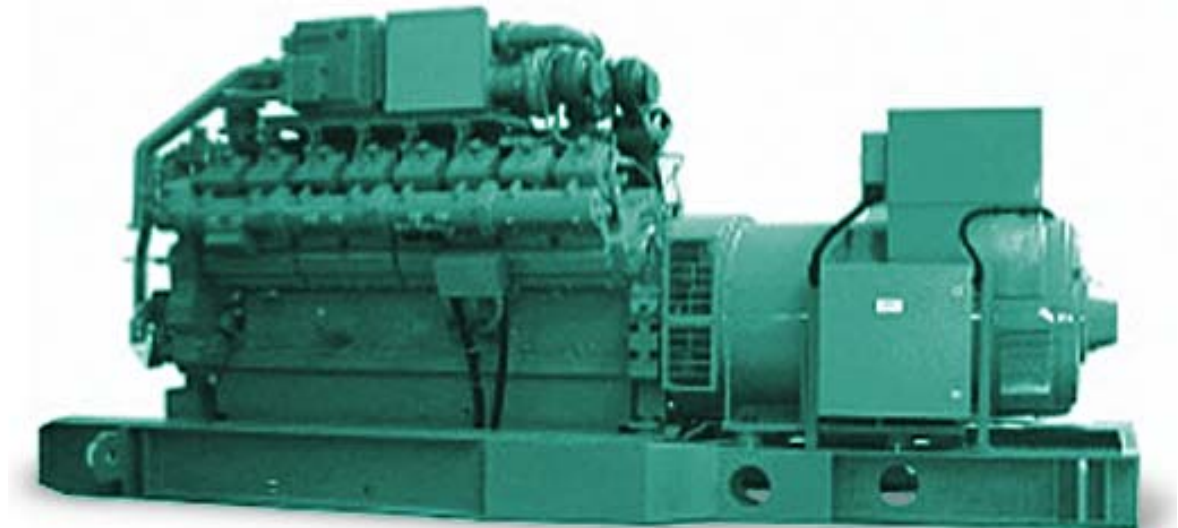
Improve closed cycle efficiency
Explore advanced combustion concepts
Improve predictive models
Improve air handling
Reduce friction contribution
Improve controls
New sensing technology
Waste heat recovery
Higher efficiency alternator
Long life ignition system
Explore aftertreatment technologies



Key technologies being explored



- High efficiency turbo charging
- Miller cycle
- Advanced lean burn concepts
- Diesel pilot ignition
- High Pressure Direct Injection (HPDI)
- Stoichiometric combustion with EGR
- HCCI
- Turbo compound
- Bottoming cycle
- High efficiency alternator



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Project Team/Partnerships



- Cummins Westport Inc. – HPDI combustion
- Colorado State University – Diesel Pilot Ignition
- Delphi – Injector development
- Ricardo – Injection simulation
- Newage – High efficiency alternator
- Oak Ridge National Lab* -- Ignition system studies
- Lawrence Livermore National Lab* – Chemical kinetics
- Lund Institute of Technology* – HCCI consortium



* Currently not funded through ARES





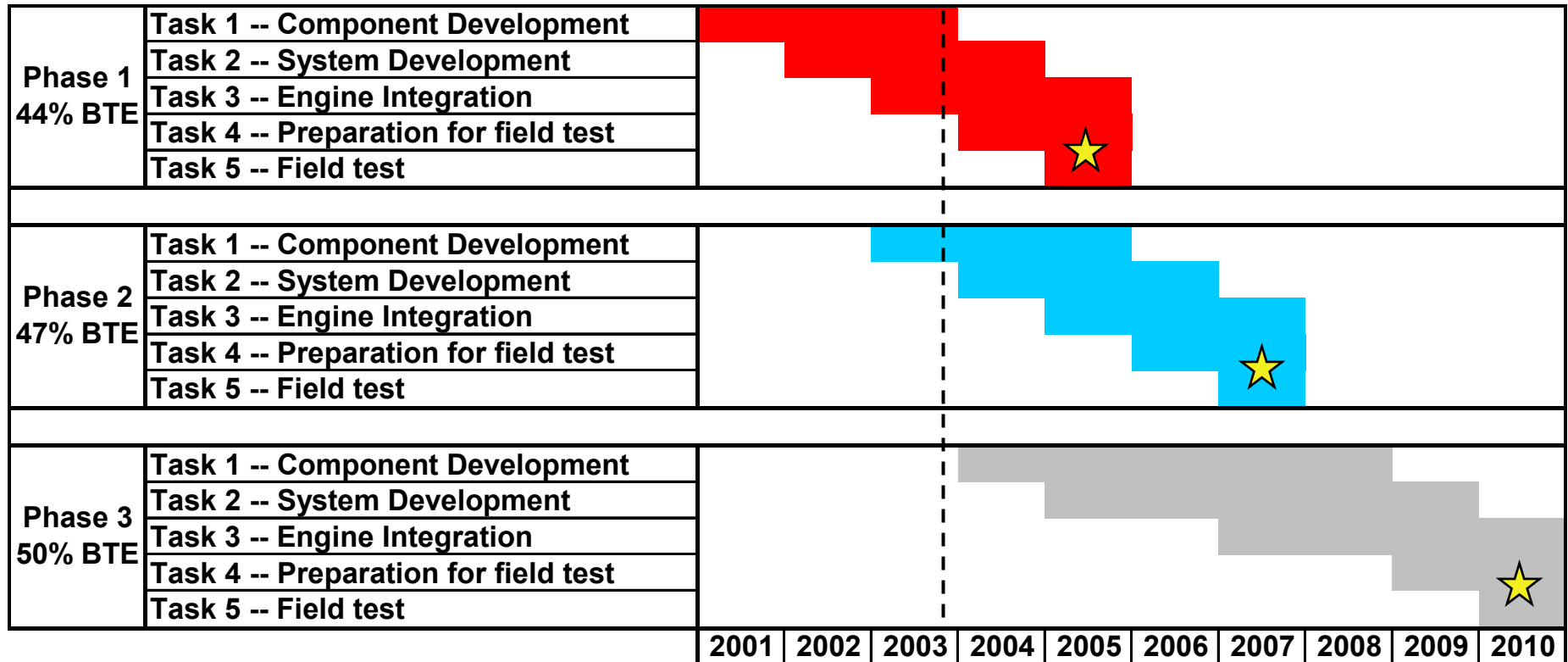
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Program Phases





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Current Milestones



Advanced Combustion Systems	Define pilot ignition design requirements	Completed
	Demonstrate diesel pilot ignition limits	Completed
	Prove next generation HPDI system performance	Completed
	Evaluate fast burn piston design	Completed
	Define combustion system design guidelines and tradeoffs	Completed
Air handling	Define limits of turbocharging and system optimization	Completed
	Define air handling system tradeoffs	Completed
	Define design concept for reduced FMEP contribution	Completed
Spark plug life	Demonstrate life limits of conventional spark ignition system	Completed
	Demonstrate life limits of new spark ignition system	Completed
Waste heat recovery	Bottoming cycle evaluation	Started
High efficiency alternator	Define design concept for high efficiency alternator	Planned



Planned Milestones for 2004



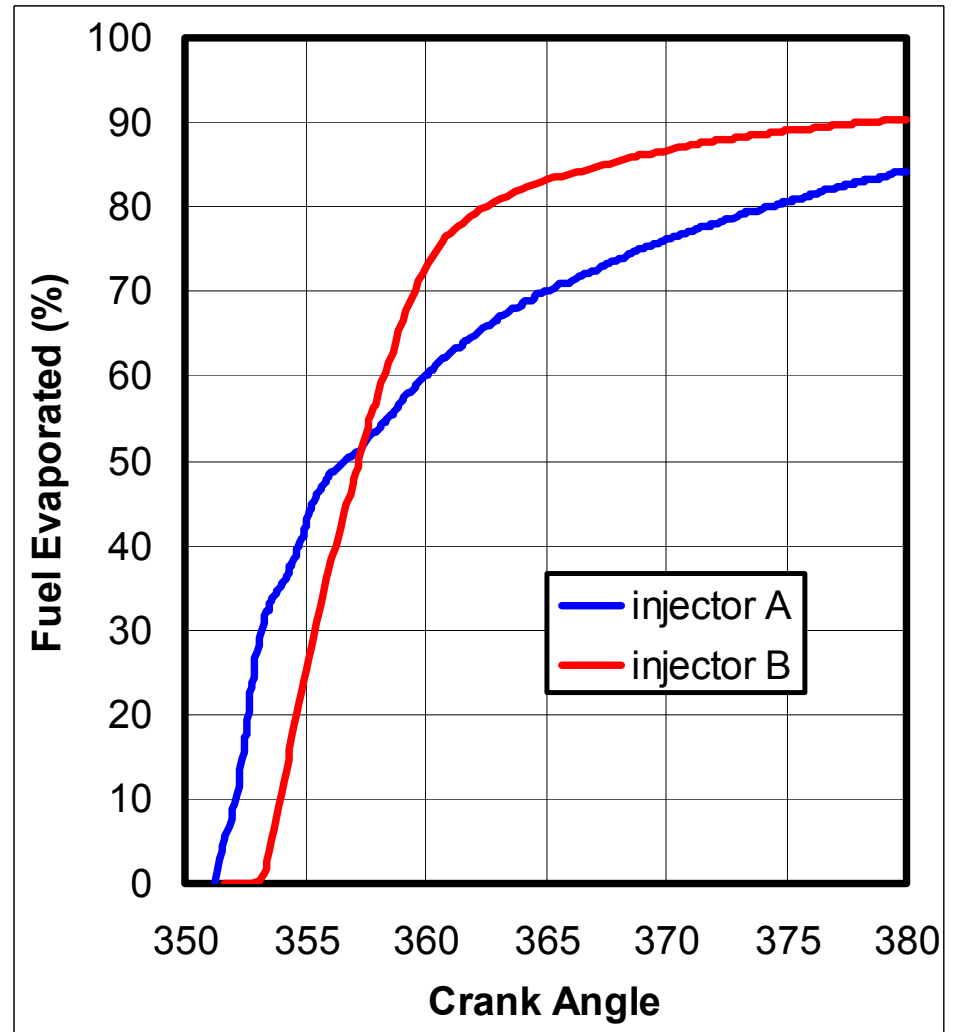
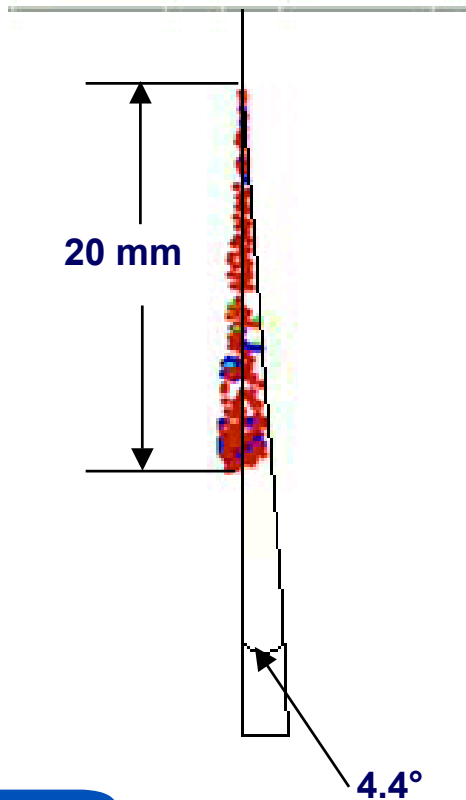
Advanced combustion systems	Demonstrate performance of field test engine for phase 1
	Evaluate performance of advanced combustion systems for phase 2
	Improved predictive models
Advanced Sensors	Demonstrate performance of combustion sensors
	Demonstrate durability of combustion sensors
Spark plug life	Demonstrate further improvement in spark plug life
Waste heat recovery	Evaluate bottoming cycle application
High efficiency alternator	Evaluate high efficiency alternator



Milestone: Pilot Ignition Design Requirements and Diesel Pilot Ignition Limits

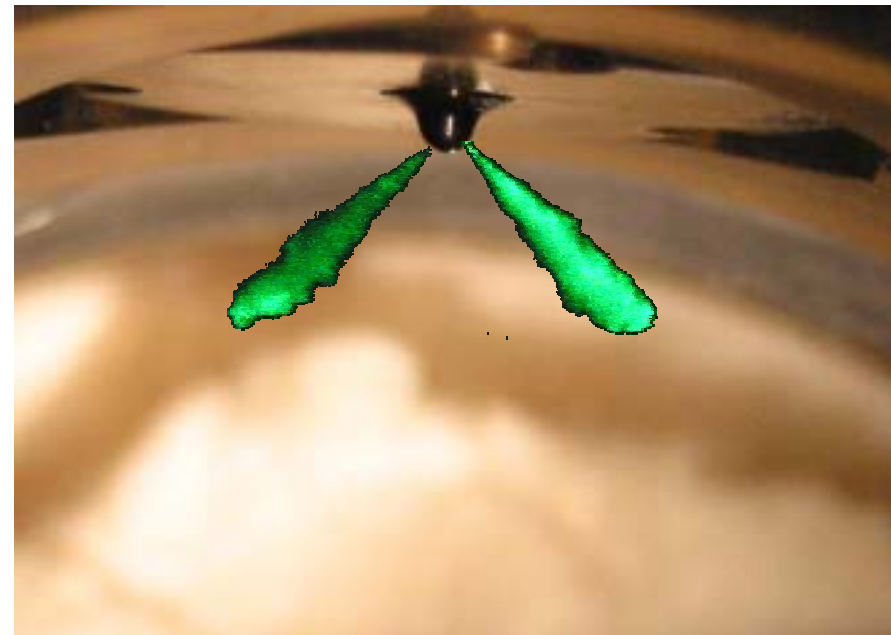
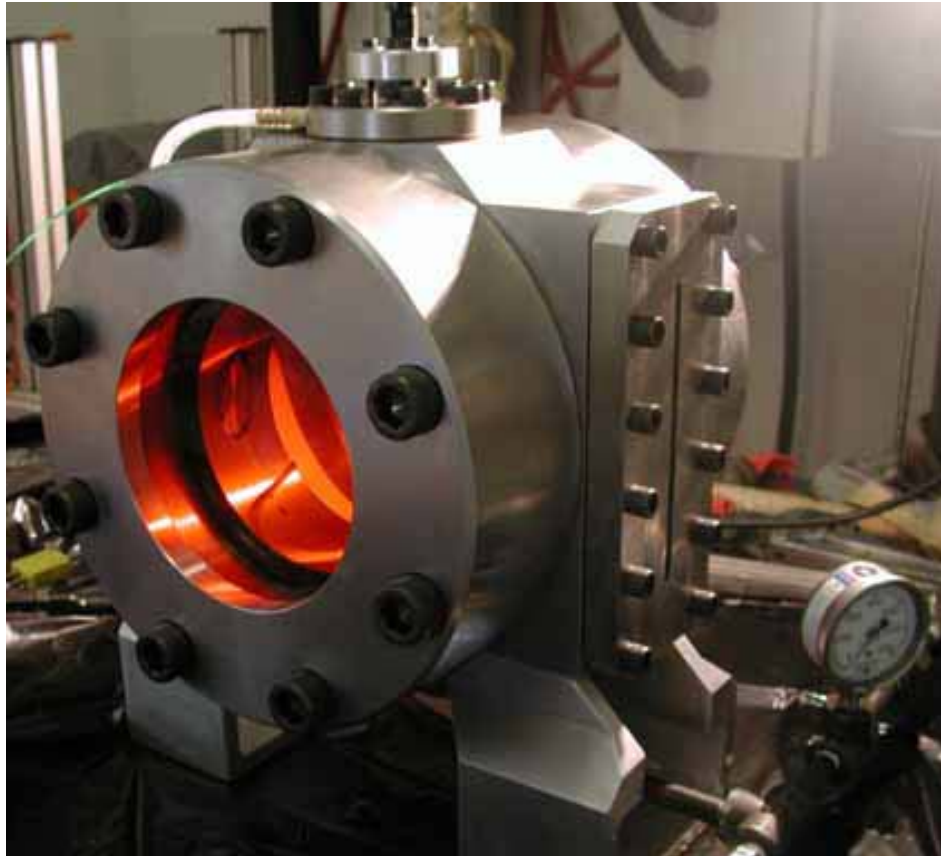


Pilot Ignition Design Requirements (Analysis)



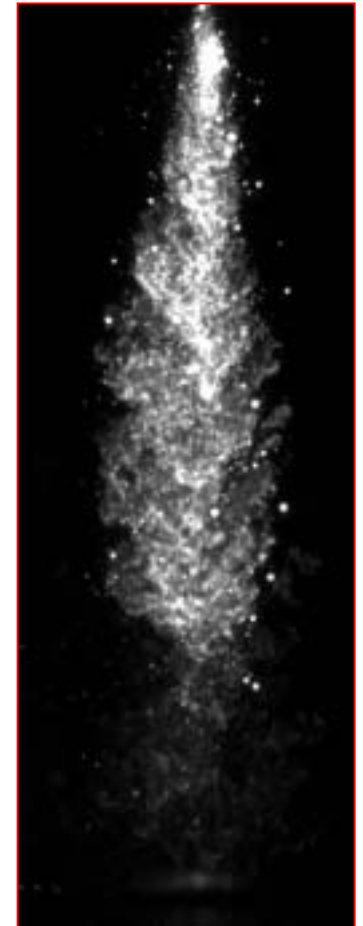
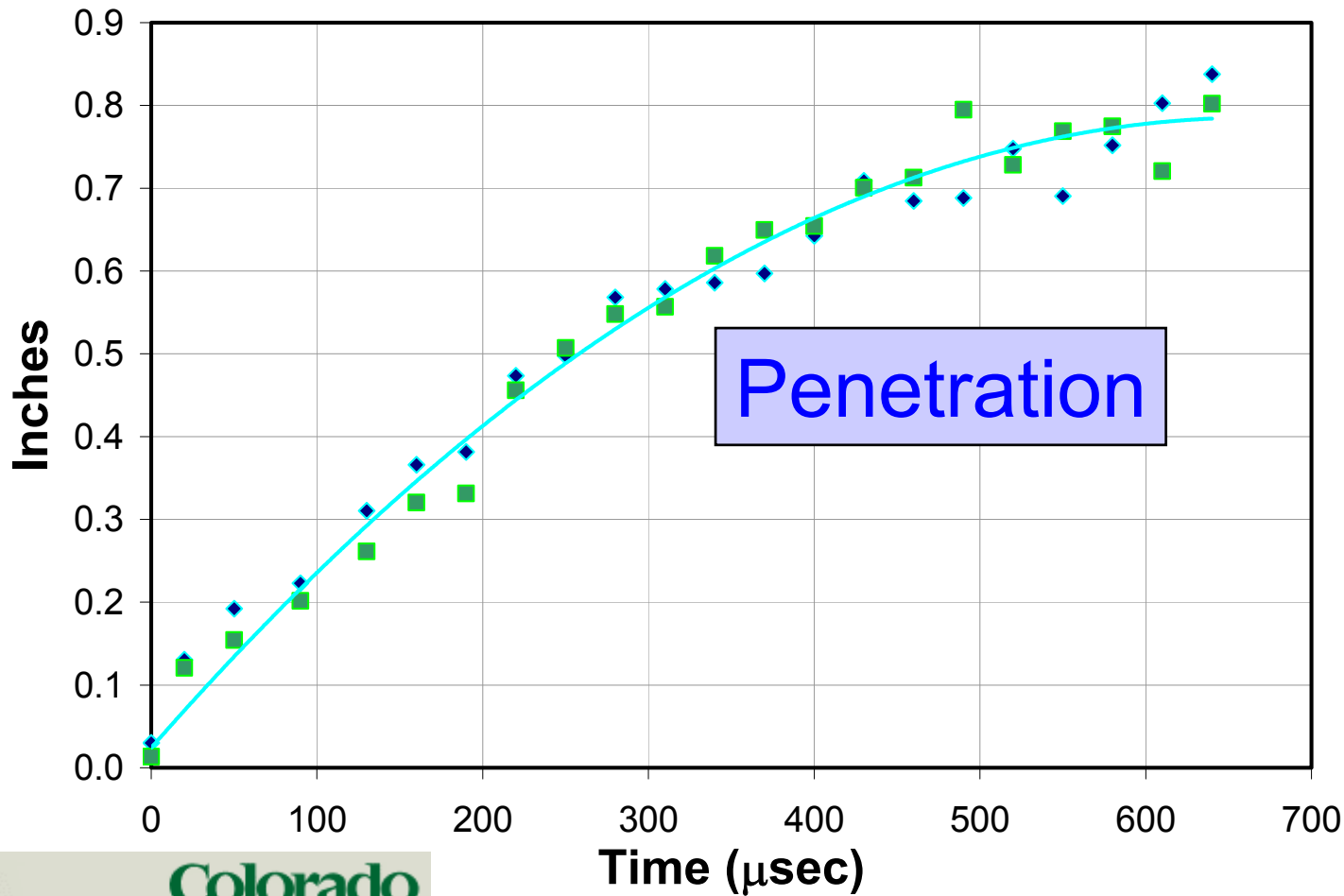


Pilot Ignition Design Requirements (Rig Test)



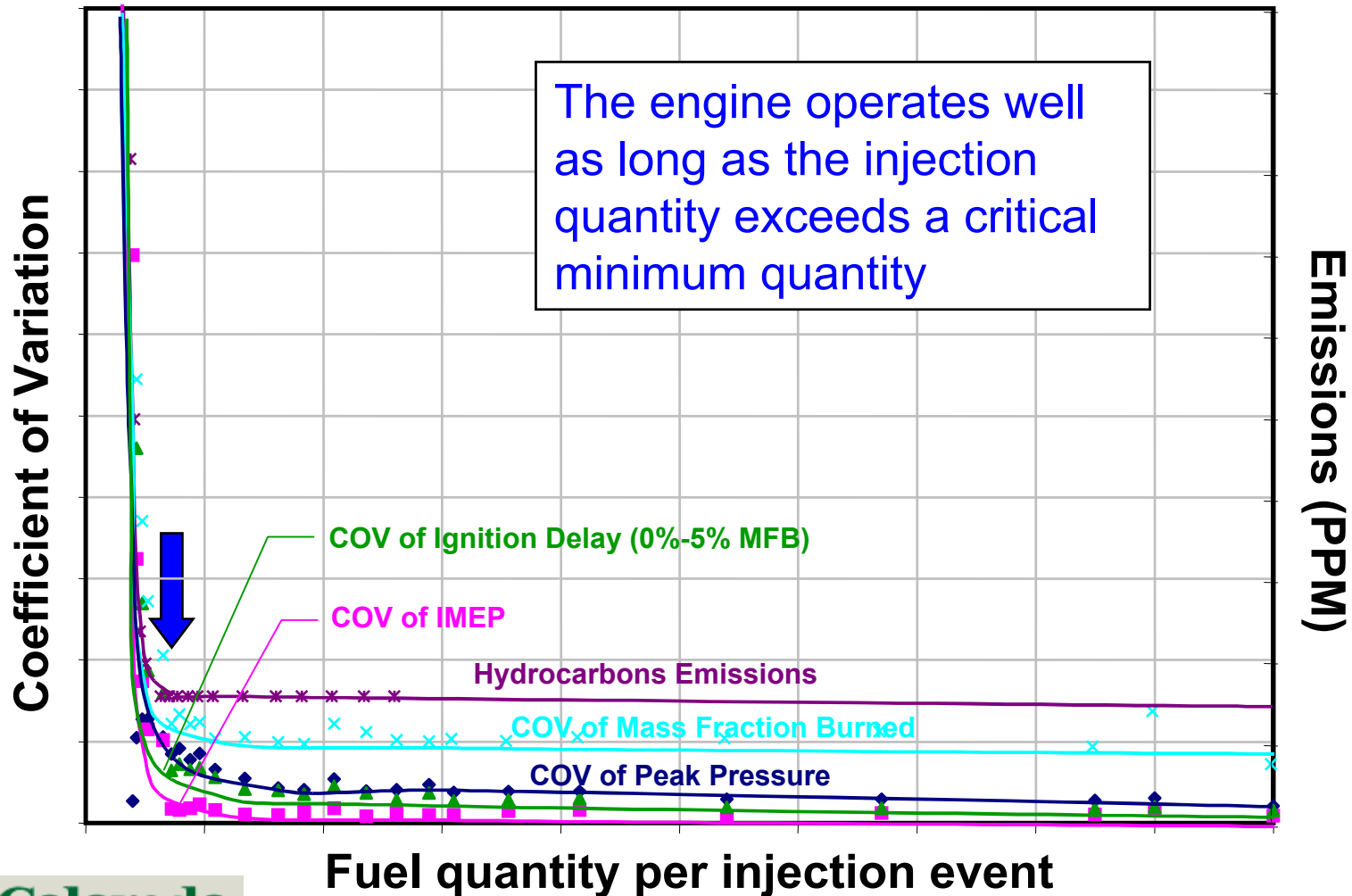


Pilot Ignition Design Requirements (Rig Test)





Diesel pilot ignition limits (Engine Test)

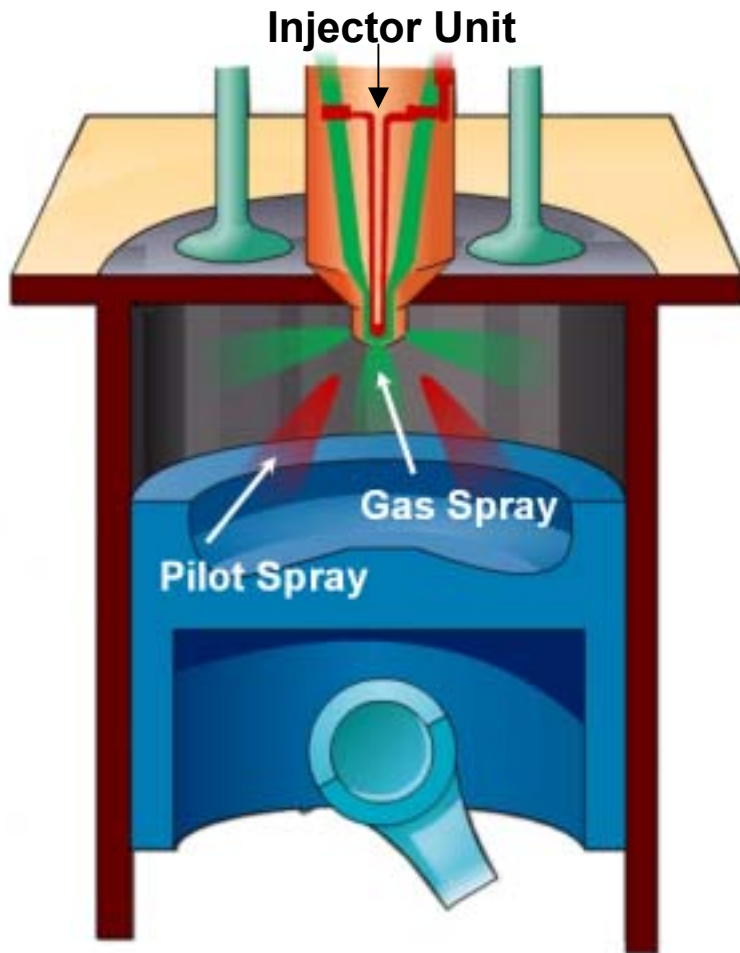




Milestone: Prove next generation HPDI performance



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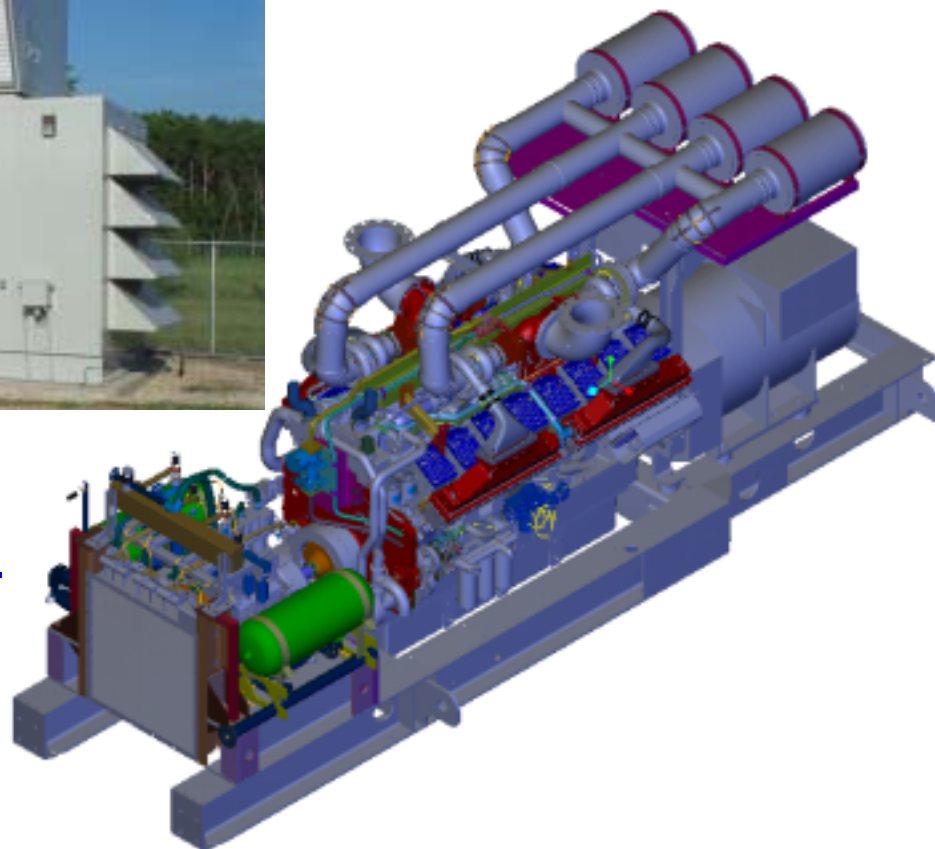
- **Direct injection of natural gas for high power density**
- **Diesel pilot is used to initiate combustion**
- **Improvements over SI**
 - Improved power and efficiency at low engine out NOx levels
 - Better transient response
 - Better compensation for CNG composition
- **20% less CO₂ than diesel combustion**



Prove next generation HPDI performance



Field test unit started operation
In Grande Prairie, Alberta in 2003.
Test unit in Anaheim, Ca about to
go operational.



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Demonstration Unit



- Field test unit started 1-year demonstration on Q3 03
- Exporting 1.6 MWe power onto the grid
- ~85% lower NOx emissions than diesel-fuelled equivalent
- ~20% less greenhouse gas emissions than diesel-fuelled equivalent
- Significantly lower PM than 2006 Tier II Standards
- No expensive aftertreatment

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Anaheim Utility Demonstration Unit



- 1.6MWe grid export demonstration, with SCR, PM Filter and continuous emissions monitoring.
- Permitted at < 0.25 g/bhph NO_x (23 ppm) and < 0.045 g/bhph PM.
 - Use of aftertreatment will exceed permitting requirements.

Packaged Genset installed on site.

Preliminary switchgear testing & commissioning complete.

Final protective relay programming required prior to grid connect.

Expect unit to start operation early Dec '03.

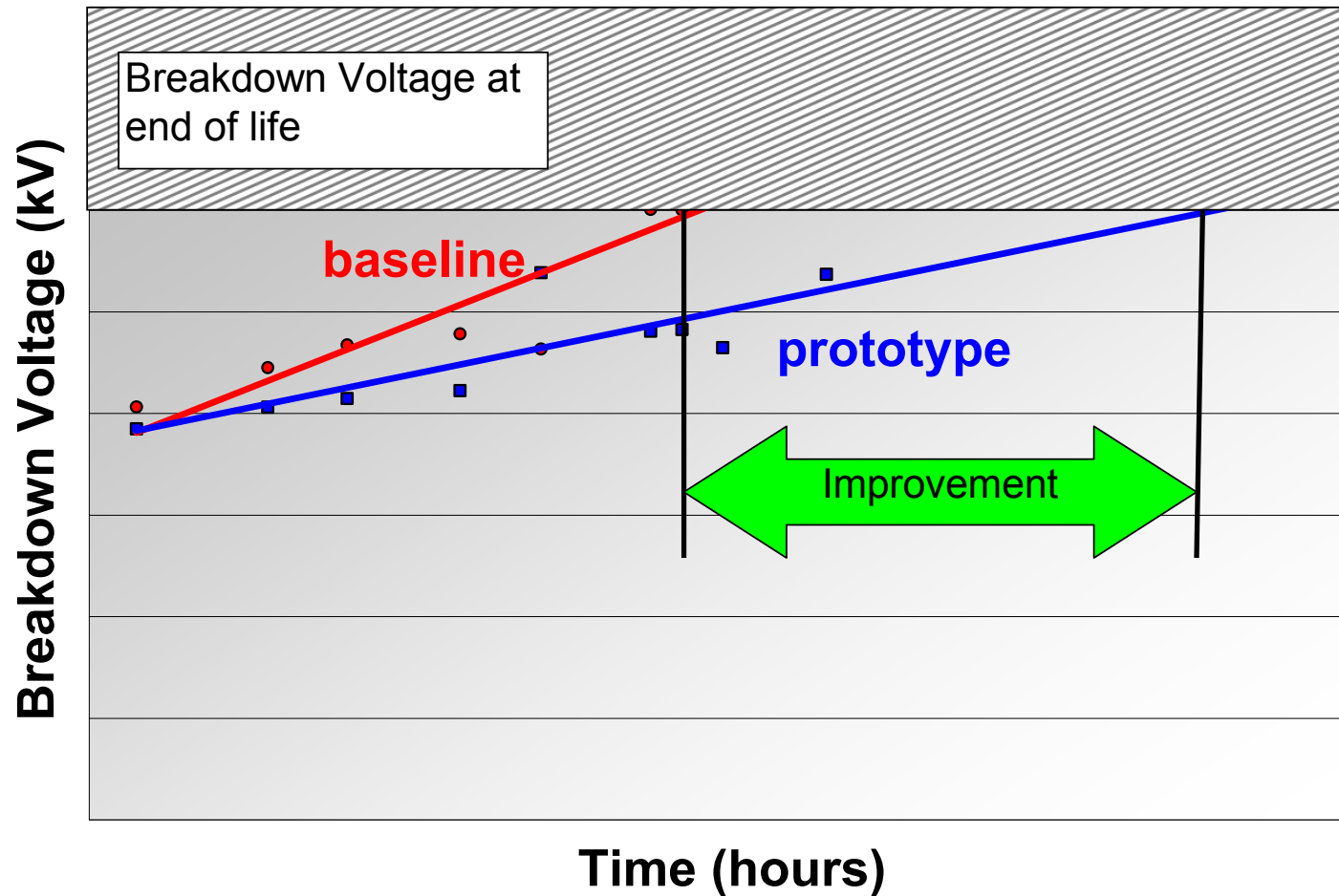




Milestone: Demonstrate Improved Life of Ignition System



Demonstrate Improved Life of Ignition System





Milestones: **Air handling** **and** **combustion systems**



Air Handling and Combustion System Milestones:



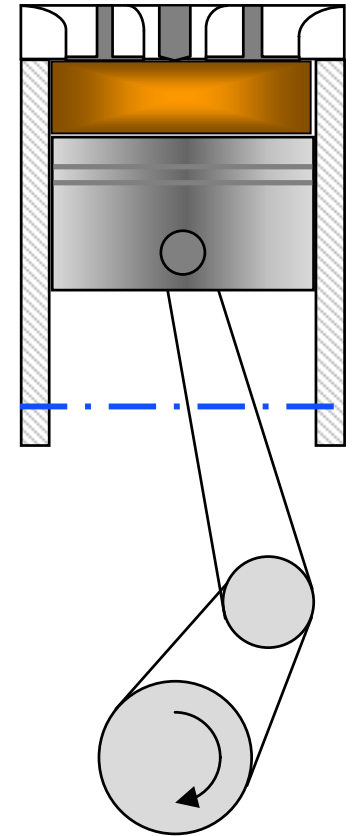
- Define limits of turbocharging and system optimization
- Define air handling tradeoffs
- Evaluate fast burn combustion chamber designs
- Define combustion system guidelines and tradeoffs



Air Handling and Combustion System

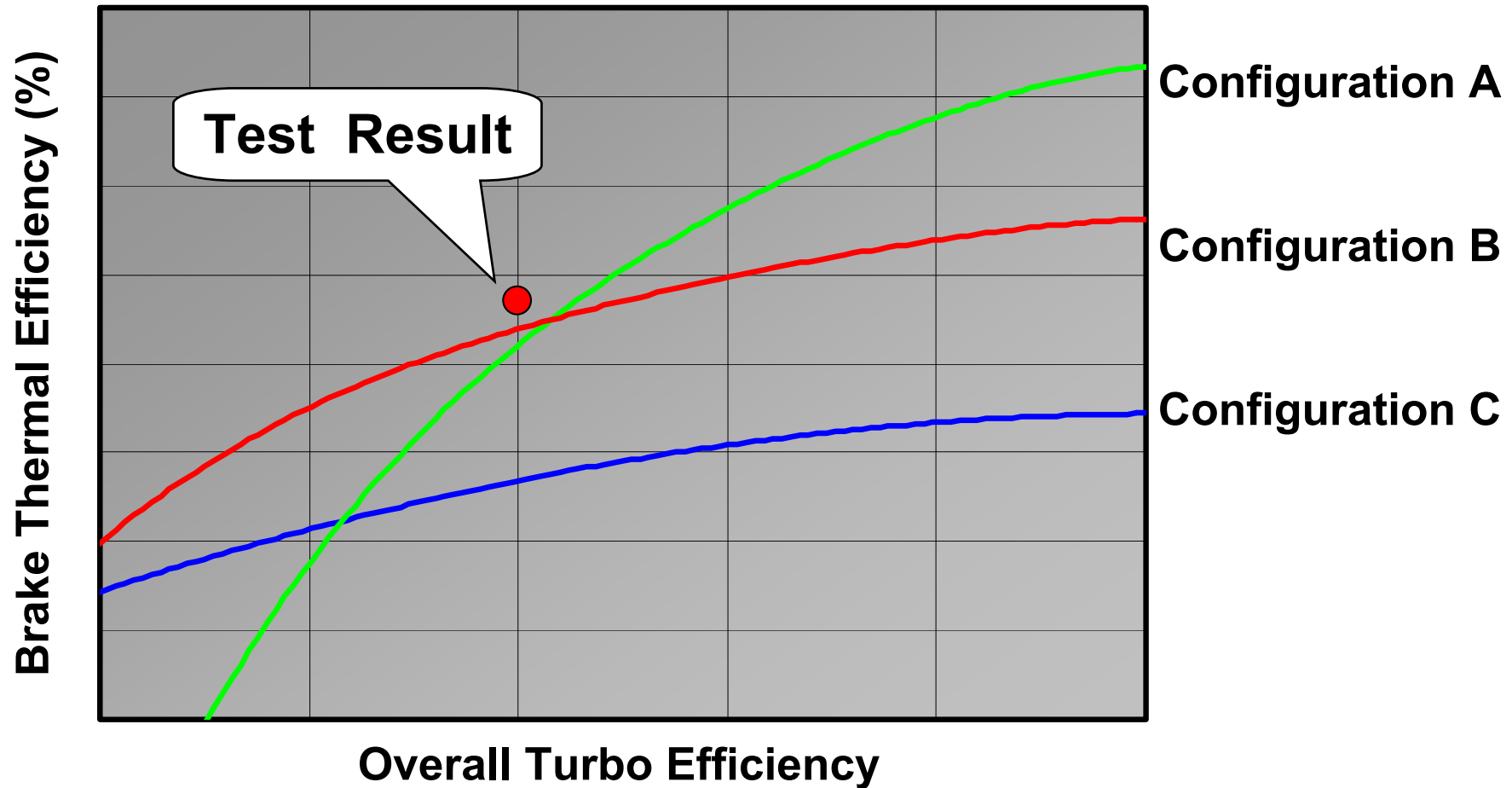


- Improved turbocharger efficiency
 - Demonstrated
- Improved closed cycle efficiency
 - Demonstrated
- Improved fuel consumption
 - 8% better than baseline





Predicted and actual performance match closely

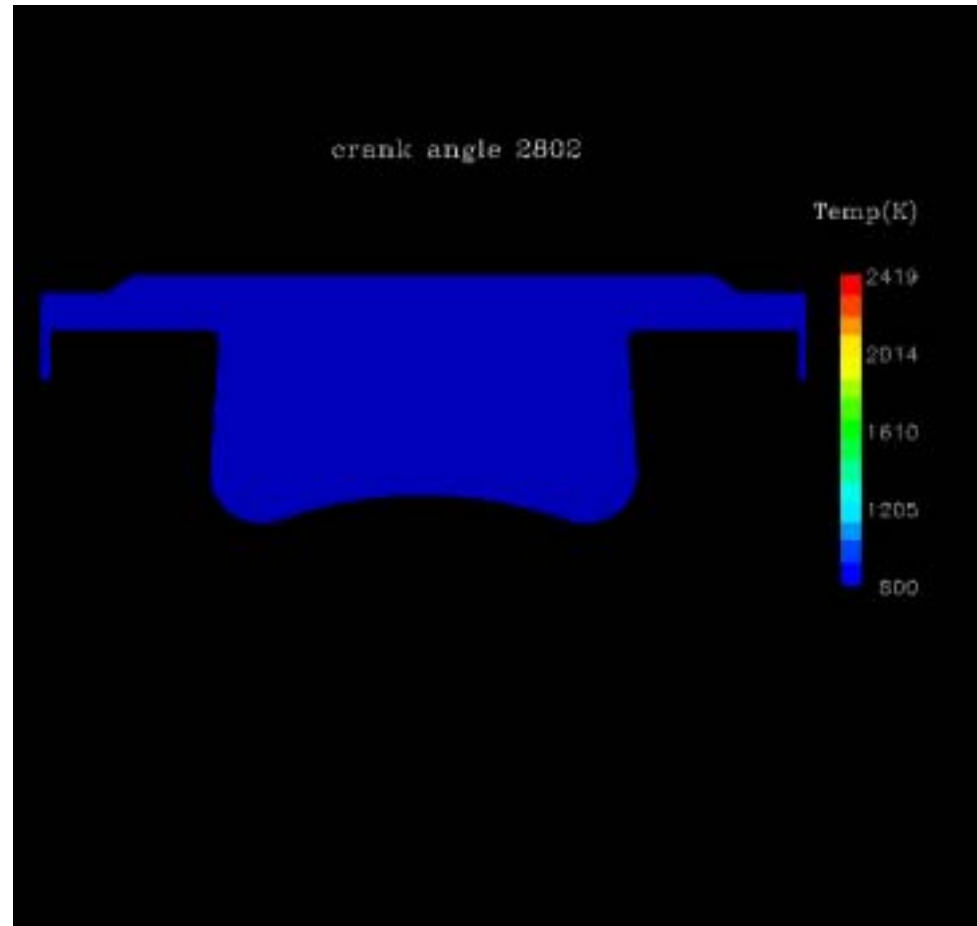




Modeling – improved CFD models for spark ignition combustion



- Improved sub-models used in CFD calculations of spark ignited combustion.





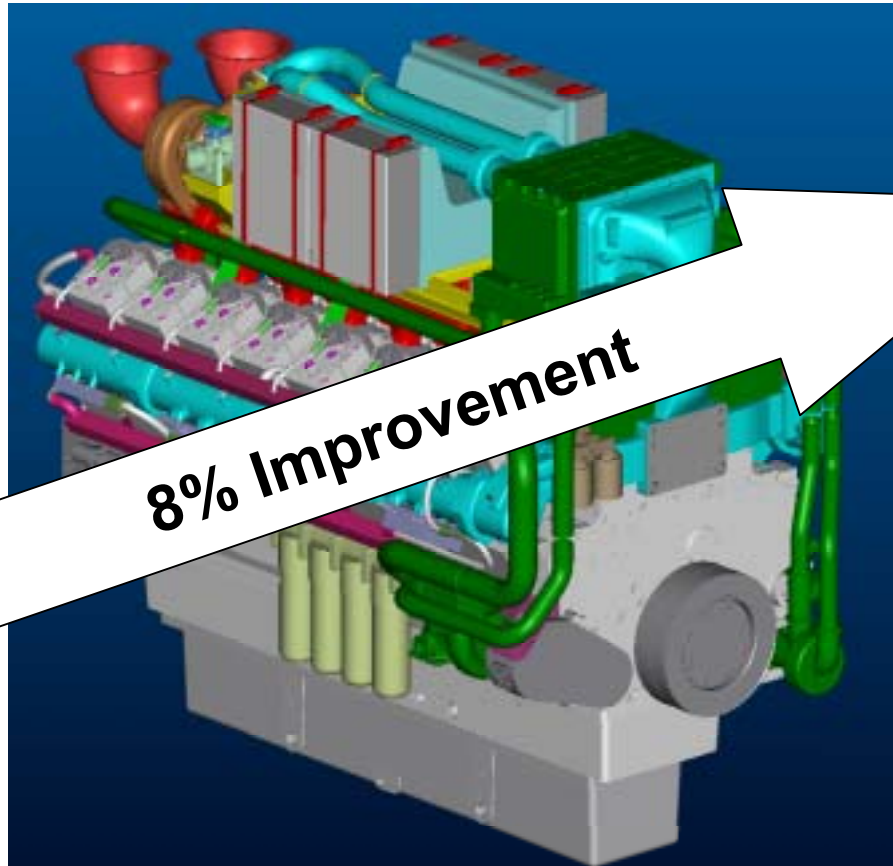
Demonstrated 8% improvement in fuel consumption vs. baseline



Baseline

8% Improvement

**ARES
Technology**





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Key technical barriers



- Need to develop higher fidelity predictive tools
- Need to develop more durable and capable combustion quality sensors
- Need to develop advanced controls to optimize advanced combustion systems
- Need to define limits and characteristics of advanced combustion systems
- Higher BMEP levels require more durable spark plugs
- Improved aftertreatment is required to reach low NO_x emissions cost effectively



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Project risks



- Some technologies may be technically feasible but not marketable (business case)
- Some technologies unproven and high risk
 - Advanced lean burn concepts
 - Diesel pilot ignition
 - Direct injection of natural gas
 - HCCI
 - Stoichiometric SI with EGR
- Combustion sensor performance and durability
- Spark plug life for high BMEP operation



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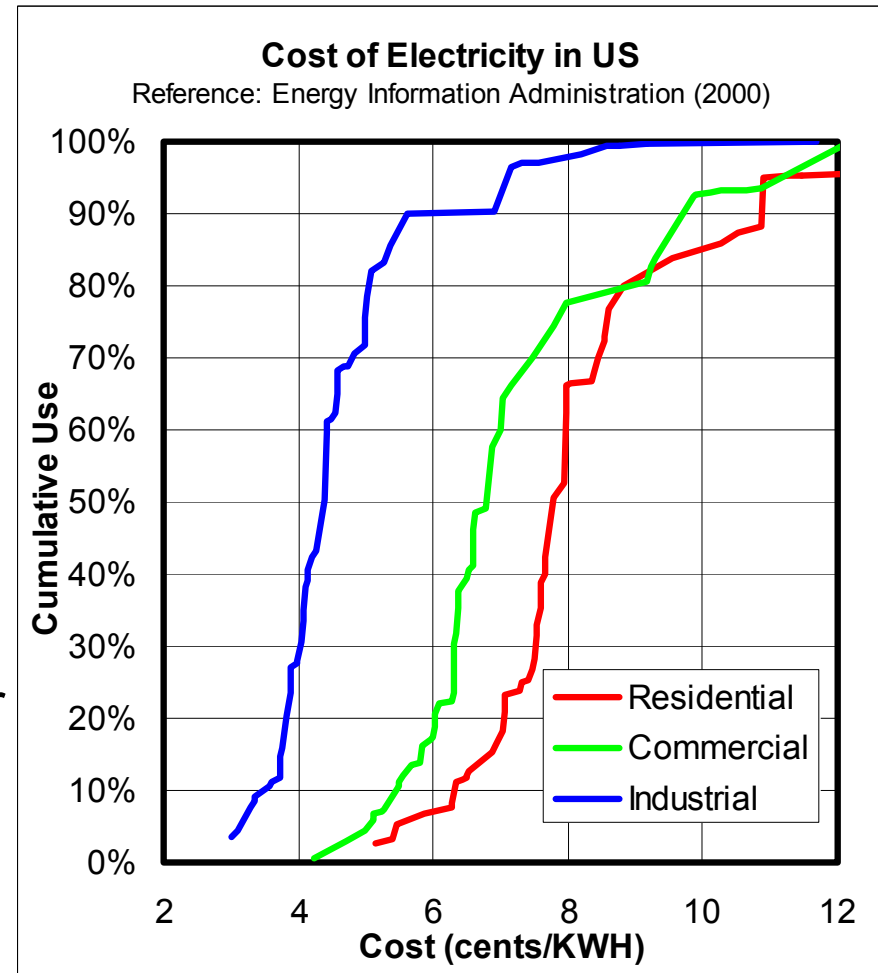
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Impact of ARES technologies on Distributed Energy Program



- Lower cost of ownership shortens payback period and broadens the potential market
- Lower emissions improve air quality
- Reduced dependence on foreign oil
- No transmission loss
- Can use natural gas in locations where diesel fuel cannot be stored
- Increased reliability of power grid due to decentralization
- Reduced CO₂ emissions vs. diesel or coal
- Distributed power creates the opportunity for waste heat utilization through CHP





Impact on Distributed Power Generation



The combination of

- high efficiency
- low cost of ownership
- low NO_x emissions



will make it more attractive for customers to purchase natural gas fueled reciprocating engines. This is expected to have a direct positive impact on distributed power generation.



Summary



- ARES technology is being introduced in Cummins Westport Inc. field test units.
- We are on track for a 2005 field test at 44% BTE.
- We demonstrated 8% improvement in fuel economy relative to baseline engine.
- ARES technologies and learnings are currently being integrated into our next generation products.
- ARES is projected to have a direct positive impact on distributed power generation through reduced cost of ownership and lower emissions.



power generation



power quality



power protection

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